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13. ABSTRACT (Maximum 200 words)

Our research has been concerned with visual surface representation and the manner in which visual image segmentation influences certain early visual processes such as stereopsis, motion correspondence, structure from motion, shape from shading, and the "aperture problem." A number of new visual effects in our laboratory (e.g., "motion capture", stereoscopic capture, etc.) have given us novel insights into the mechanisms underlying human motion perception and stereopsis.

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February 18, 1993

Dr. John Tangney
AFOSR, Building 410
Bolling Airforce Base
Washington, D.C. 20332-6448

Dear John,

Here it is at last - the proposal I promised to send you 6 months ago! Following your advice I have kept it "conservative." We will also be working on phantom contours, filling in etc., but we have left these out in the interest of brevity.

The proposal deals mainly with the important but neglected problem of visual surface representation - especially the role played by segmentation in this process. As you know, our laboratory has been involved in the discovery of several novel perceptual effects such as 'motion capture' and stereoscopic capture. Our goal will be to continue this research and to obtain more detailed parametric data on these illusions.

As you can see our work is quite critical of David Marr and should therefore not be reviewed by any of his former disciples or associates. It should be kept in mind, however that although our experiments have called into question whole classes of models, they have also inspired several new computational models of motion processing and stereopsis(e.g. by Bulthoff, Yuille, and others).

We would also prefer that it was not reviewed by Gibsonians. On the other hand, any eminent perceptual psychologist would be appropriate as a reviewer, e.g. Triesman, Julesz, Cavanagh, or Rock.

I enclose a summary of what we have accomplished during the last 3 years that we have received funding from your agency. We look forward to your continued support.

With best regards,

Rama

V.S. Ramachandran, M.D., Ph.D.
Professor of Neurosciences
and Psychology

Final Report -
G-AFOSR 89-0414
V.S. Ramachandran
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FINAL PROGRESS REPORT/AIRFORCE OFFICE OF SCIENTIFIC RESEARCH

Our research is concerned with the question of how the visual system creates 3-D representations of surfaces. The last two or three decades have seen breathtaking progress in the three disciplines -- cognitive psychology, AI and visual neurophysiology -- but they have been pursued more or less independently. Our research suggests that the time is now ripe for forging links between these disciplines for an integrated approach to vision.

We have had two goals in mind:

1. To develop conceptual links between neurophysiology and perception;

2. To develop specific tests for computational models of human vision.

While it is true that some of our work has called into question whole classes of "models" they have also inspired several new computational models (e.g., models of "motion capture" proposed by Bulthoff, Yuille, Koch and others).

During the last decade the work of David Marr (1981) has had a tremendous impact on our field -- mostly positive. Indeed, his work has revolutionized the study of vision in a manner analogous to the Chomskyan revolution in linguistics. There are, however, several major pitfalls associated with his approach. Consider the four basic pillars on which Marr's edifice rests:

1. Complex information processing systems -- such as human vision -- can be studied at different "levels" -- i.e., the abstract level of the "computational problem," the level of algorithm and the level of hardware implementation. Marr urges us not to get "confused" between these levels -- they must be kept quite separate if we wish to avoid getting into conceptual muddles.

2. The most important critical step in understanding any visual process is to clearly formulate the "computational problem" preferably in formal mathematical language.

3. "Segmentation" of the visual image is a complex, ill posed, and largely intractable problem in AI. Fortunately, however, many of the processes of early vision, e.g., stereopsis, motion correspondence, structure from motion, shape from shading, etc., take place <u>prior to</u> image segmentation. In fact their output can <u>lead to</u> segmentation (e.g., Julesz' stereograms). Therefore we can study and model these processes without worrying too much about segmentation.

4. "Top down" processes based on high level semantics have no role in human vision.

These four assumptions seem reasonable enough at first glance, but our work suggests that none of them really holds up on careful scrutiny. Let us consider each in turn.

1. The argument about levels may be valid as a logical point (one recalls Gilbert Ryles remarks about "category mistakes") but from a <u>strategic</u> point of view the advice is misguided. In our view the only sure way to progress in understanding any <u>biological</u> information processing system -- such as vision -- is to develop conceptual links between levels instead of trying to keep them separate. As an analogy consider the manner in which our understanding of the double helical structure of the DNA molecule (i.e., the "hardware") completely transformed our understanding of classical heredity and genetics which, until then, had remained a "black box" subject. There is now a wealth of empirical evidence that the same principle holds for understanding human vision, i.e., the neural machinery in our visual pathways

powerfully constraints our perceptual experience of the world (e.g., Ramachandran & Gregory. 1978; Ramachandran, 1987; Ramachandran, 1991; Ramachandran & Gregory. 1991; Rogers-Ramachandran, Ramachandran, 1991, ARVO). For example, we have now devised a stimulus that seems to selectively activate a "fast" sign-invariant contour processing system in human vision that might correspond to the "magno cellular pathway" of physiologists.

2. Understanding the "computational problem" is certainly important, as emphasized by Marr, but it is very easy to prejudge what the problem actually is unless you do experiments. e.g., what is the computational goal of color vision? Also "computational problems" such as stereo correspondence, structure from motion and the aperture problem were first identified by doing experiments (e.g., by Julesz, Wallach and others) and they were not deduced from first principles.

3. Work done in our lab contradicts Marr's claim that segmentation does not influence early vision modules. What we find in fact is that image segmentation produced by cues such as implied occlusion, for example, can powerfully constrain the solution to many early vision problems such as motion correspondence (Ramachandran, 1985; Ramachandran, 1991) stereopsis (Ramachandran, 1986), structure from motion (Ramachandran, Cobb & Rogers-Ramachandran, 1986); and shape from shading (Ramachandran, 1988). Any program of research on vision must take these facts into account.

For example, we have done several experiments which suggest that even illusory contours (defined by implied occlusion) can profoundly influence the processing of stereopsis, apparent motion and shape from shading.

4. The view that "top-down" processes play no role in human vision is contradicted by the simple observation that hollow masks do not look hollow, they look convex. This is true even when the visual system has to override stereoscopic disparity (Helmholtz, Gregory, 1976) or the assumption of overhead lighting (Ramachandran, 1988).

One could argue, however, that this tendency has nothing to do with familiarity with faces. The illusion may arise from a generic assumption about the convexity of objects rather than familiarity with faces. To test this, we recently tried comparing an upside-down hollow mask with a hollow mask held upright. By walking away from the mask until it just reversed (i.e., was seen as convex), we found that larger disparities can be overridden by the latter than by the former. Since the masks are otherwise completely identical, the observed difference has to be a result of the fact that upright faces are more "face-like" than upside-down ones. Thus, while it is largely true that early vision is relatively immune from semantics -- our experiments suggest that Marr has clearly overstated his case.

In summary, our research has called into question several widely accepted dogmas concerning the mechanisms of early vision. Also, we have been able to discover several novel visual phenomena (e.g., motion capture, stereo-capture, etc.) and have identified a wide range of new "natural constraints" that govern the perception of shape-from shading (Ramachandran, 1988; Kleffner & Ramachandran, 1992), structure from motion and motion correspondence. Also, we have discovered striking perceptual correlates of several well-known physiological observations (e.g., "phantom contours" -- stimuli which selectively activate the magnocellular pathway; "filling in" of scotomas described by Gilbert & Wiesel, Gaines & others; plasticity of cortical topography, described by Merzenich, Pons and Gatas).

The enclosed reprints provide more detailed descriptions of research that we have been doing along these lines.

List of Publications

1. Stoner, G., Albright, T., & Ramachandran, V. S. (1990). Transparency and Coherence in Human Motion Perception. *Nature, 344*, 153-155.

2. Ramachandran, V. S., & Anstis, S. M. (1990). Illusory displacement of equiluminous kinetic edges. *Perception, 19*, 611-616.

3. Deutsch, J. A., Ramachandran, V. S. & Peli, E. (1990). Binocular depth reversals despite familiarity cues: An artifact? *Science, 249*, 565-566.

4. Nakayama, K., Shimojo, S., & Ramachandran, V. S. (1990). Transparency: Relation to depth, subjective contours, luminance, and neon color spreading. *Perception, 19*, 497-513.

5. Ramachandran, V. S. (1990). Visual percetion in people and machines. AI and the Eye. Sussex, England: John Wiley and Sons, 21-77.

6. Ramachandran, V. S. & Gregory, R. L. (1991). Perceptual filling in of artificially induced scotomas in human vision. *Nature, 350*, 699-702.

7. Ramachandran, V. S. & Rogers-Ramachandran, D. C. (1991). Phantom contours, a new class of visual patterns that selectively activates the magnocellular pathway in man. *Bulletin of the Psychonomic Society*, 29, 391-394.

8. Ramachandran, V. S. (1991). Form, motion, and binocular rivalry. *Science, 251*, 950-951.

9. Kleffner, D. & Ramachandran, V. S. (1992). On the perception of shape from shading. *Perception and Psychophysics*.

10. Ramachandran, V. S. (1992). Visual perception: A biological perspective. *Neural Networks in Visual Processing*.

11. Ramachandran, V. S. (1992). 2-D or not 2-D: That is the question. *The Artful Brain*, Oxford: Oxford University Press.

12. Plummer, D. J., & Ramachandran, V. S. (1992). Perception of transparency in stationary and moving displays, perception and psychophysics. *Perception and Psychophysics*.

13. Ramachandran, V. S. (1992). Blind spots. *Scientific American*, May 1992, 266, 86-91.

14. Ramachandran, V. S. (In press). Filling in gaps in perception: Part I. *Current directions in psychological science*.

15. Ramachandran, V. S. (In press). Filling in gaps in perception: Part II. *Current directions in psychological science*.

16. Ramachandran, V. S., Stewart, M. & Rogers-Ramachandran, D. (1992). Perceptual correlates of massive cortical reorganization. *Neuro. Report, 3*, 583-586.

Books

1. Appointed Editor-in-Chief of a four volume *Encyclopedia of human behavior*. Academic Press.

2. Two book contacts for the *Scientific American Library* series - one on the human brain with Patricia Churchland and the other on "seeing."

Invited lectures, appointments, colloquiua etc.

1. Invited to give the presidential lecture at the Annual Meeting of the Society of Neuroscience, Phoenix, AZ.

2. Invited to give a public lecture at the 250th anniversary celebration of the University of Pennsylvania School of Medicine.

3. Invited speaker at the annual meeting of the Neurosciences research program (NRP) held at the Rockefeller Institute (March, 1991).

4. Invited "keynote" speaker at the SPIE meeting, San Diego (1992).

5. Invited "keynote" speaker at SIGRAPH, 1992, held in Chicago.

6. Invited speaker at special symposium on "Neuronal Group Selection" at the Rockefeller Institute (NRP), May, 1992, organized by Max Cowan and Gerald Edelman.

7. Kenneth Craik lecture given at Cambridge University.

8. Colloqium given at MIT.

9. Colloquium given at Oxford University.

10. Awarded "Certificate of Appreciation for Outstanding Contributions to Visual Science" by the Optometric Association of America.

11. Appointed McDonnel Pew Visiting Fellow, Oxford University, England.

12. Interviewed on BBC television ("Antenna"). Debate with Daniel C. Dennett. Aired on August 8, 1992.

13. Interviewed on PBS television (KCET, LA) for a program entitled "Inside Information" which aired nationally.